# Solid Oxide Fuel Cell Residential Cogeneration

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# Introduction

– **Fuel cells are attractive alternatives for stationary applications.**
  - **high power generation efficiency**
  - **low emissions**
  - **low-noise characteristics**

– **Fuel cells face the typical commercialization dilemma.**
  - **in order to significantly penetrate the market, production costs must be reduced.**
  - **in order to achieve significant cost reduction, the cumulative production must be greatly increased, implying that significant market penetration must occur.**

# Introduction (cont)

- One approach that minimizes the financial and technical risks
  - initial market entry of small-scale systems into high-value stationary applications (Residential Cogeneration).
- Small scale systems would achieve rapid cost reductions from the economies of production (i.e., the manufacture of large number of identical units) as opposed to the economies of scale.

# Fuel Cells for Residential Application

- A number of companies are pursuing the development and commercialization of small scale PEM fuel cells for residential application.

- Because SOFCs run efficiently at high temperatures, they are quite suitable for combined heat and power residential applications as well.

- What advantages (if any) might SOFC-based systems have in residential cogeneration applications?

# Residential Cogeneration Requirements

- Comparable performance in meeting the residential customer's electric and thermal loads.
- Cost to residential customer should be equal to or less than current service.
- Same reliability as utility grid-connected service
- Low emissions and negligible noise and vibration (< 20 ppm NOx)
- Volume and footprint of fuel cell system should be commensurate with residential HVAC systems (< 7 ft3 / kW).

# Residential Cogeneration Requirements

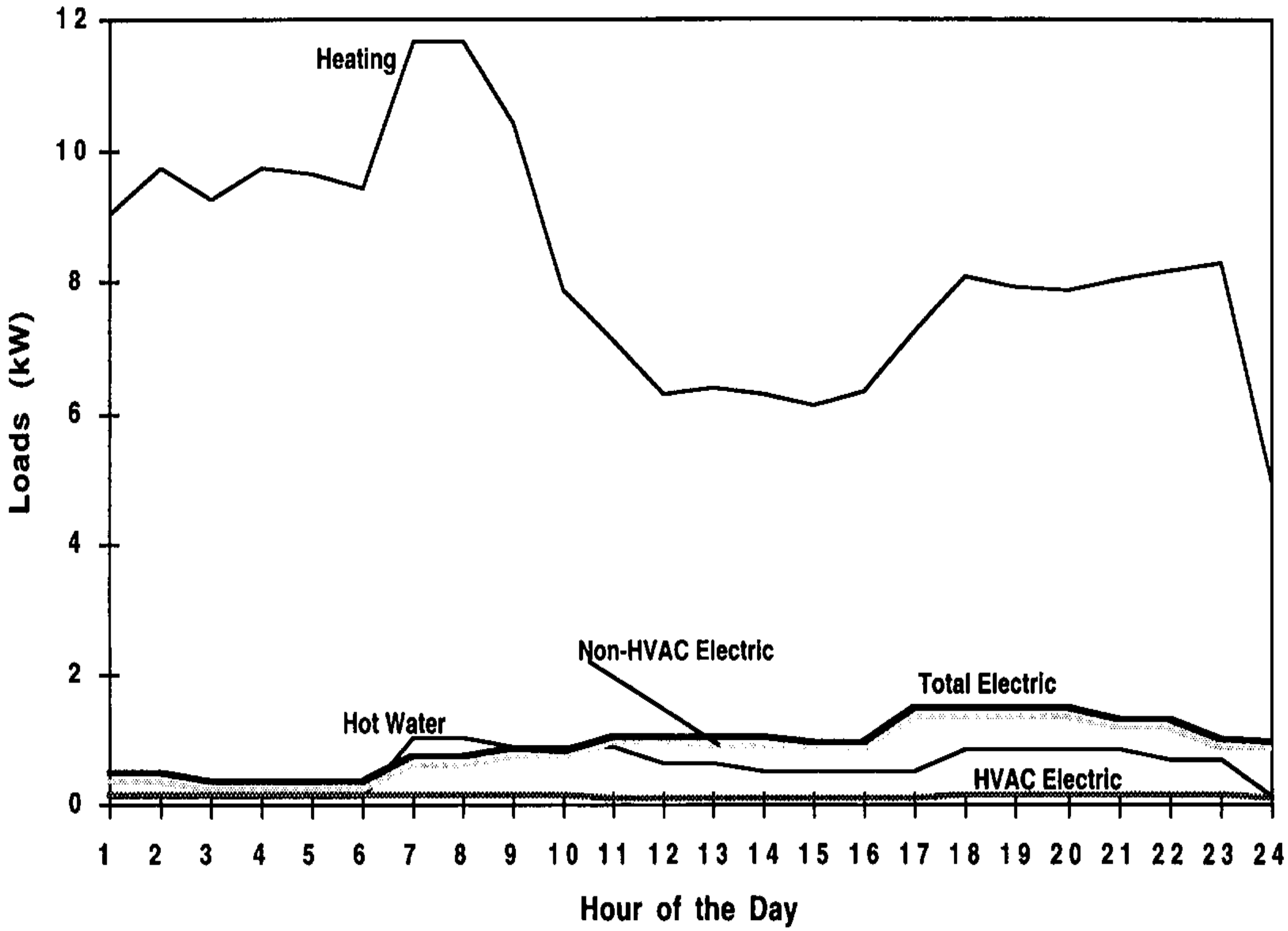
– **Necessary to take into account the daily and seasonal variations in both the electric and thermal loads.**

– **Would like electric and thermal loads to be coincident to make optimum use of cogeneration energy produced**

– **The ratio of thermal to electric energy (T/E) of typical homes can range**

  - **as high as 9 in the winter (when thermal loads for space heating are high).**
  - **as low as 0.2 in the summer (when electric loads are high for air conditioning and the only thermal loads are for hot water).**

# Residential Load Profiles (winter)




**Thermal and electric load profiles for the peak winter day in a northern climate.**

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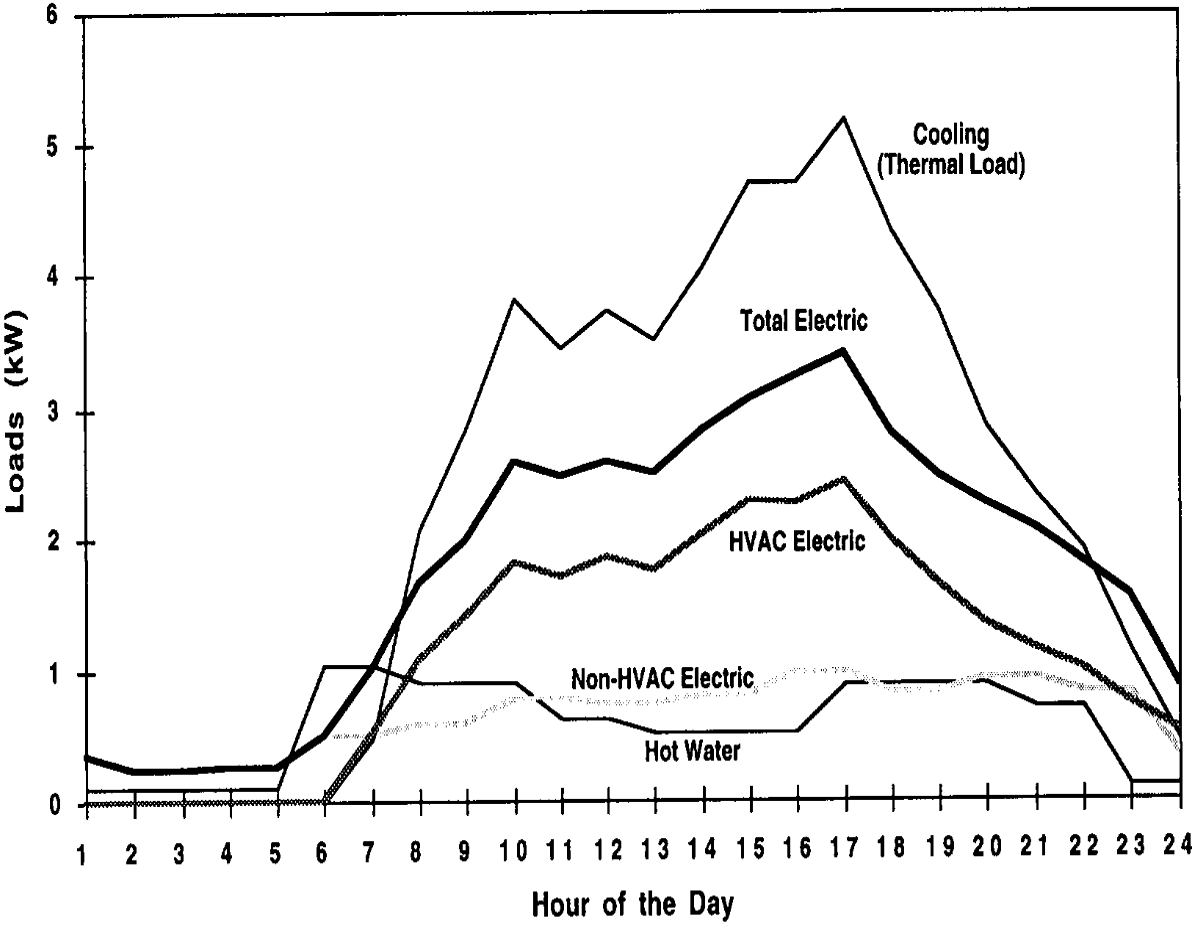
# Residential Load Profiles (summer)




**Thermal and electric load profiles for the peak summer day in a northern climate.**

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# Suitability of Fuel Cell-Based Systems for Residential Cogeneration

- On average, residential electric loads (not including air conditioning) are about the same as the hot water loads (T/E of 0.6 - 1.0).
- Internal combustion engine cogeneration systems (e.g., Kohler system) have relatively high T/E ratios.
  - T/E=2.7 operating in electric demand mode
  - T/E=17.4 operating in thermal demand mode
- Fuel cell systems have a T/E ratios of approximately 1.
- Fuel cells are better matched with base-load requirements of residential applications.



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# Define How Will Fuel Cell Be Used

– **Will fuel cell be operated in grid-connected mode or grid-independent?**
– **Will fuel cell be operated in base load configuration or as a peak load following power source?**
– **If grid-independent and peak load following, what is the means of energy storage to handle peak demands?**


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# Suitability of Fuel Cell-Based Systems for Peak Load Following Operation

- Fuel cells operate efficiently at part load.
- Overall efficiency of a fuel cell system that includes a fuel processor tends to be constant between 50% and 100% of rated power because of a trade-off between the fuel processor and the fuel cell stack.
  - fuel processor has lower efficiency at part load due to heat transfer losses and parasitic power requirements.
  - fuel cell stack has higher efficiency at part load.
- Fuel cells have fast reactive power response to handle instantaneous peaks.

# Comparison of Issues for PEMFC and SOFC

| Issues | PEMFC | SOFC |
|---|---|---|
| **Operating Temperature** | Fuel Cell: 80-100 $^{o}$C<br>Reformer: 650-1000 $^{o}$C | 650-1000 $^{o}$C |
| **$CH_4$ Reforming** | External | External or Internal |
| **CO Management** | CO is an anode poison Requires CO removal to reduce to <10 ppm levels. | Participates in water-gas shift reaction in anode compartment. |
| **Sulfur Management** | Sulfur is an electrode poison. Requires sorbent bed to reduce to <5 ppm levels. | More tolerant to sulfur but sulfur removal still required. |
| **Water Management** | Membrane performance sensitive to dehydration. Humidification required for anode and cathode streams | Not an issue.<br>Water generated in anode compartment participates in water-gas shift reaction |



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# Comparison of Issues for PEMFC and SOFC

| Issues | PEMFC | SOFC |
|---|---|---|
| **Heat Quality** | Low grade waste heat (70-90$^{o}$C) | High quality waste heat (650-1000$^{o}$C) |
| **Cogeneration Capabilities** | Moderate heating of water to 50-60$^{o}$C. | Aid in endothermic reforming, heating of water, space heating. |



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# Comparison of Fuel Cell Systems for Residential Application

| **Fuel Cell System:** | **SOFC** | **SR-PEMFC** | **POX-PEMFC** |
|---|---|---|---|
| **System Efficiency (LHV)** | 45% | 40% * | 35.8% * |
| **Relative Fuel Usage for Same Electrical Output:** | 1.0 | 1.12 | 1.25 |
| **Fuel Contribution to Cost of Electricity:** | 3.04 ¢/kWh | 3.41 ¢/kWh | 3.82 ¢/kWh |
| **Allowable Capital and O&M Costs (including energy storage) **** | $ 3,376 | $ 3,150 | $ 2,900 |

* The difference in performance of the two PEMFC systems is attributable to the difference in the efficiencies of the fuel processors.

** Based on 15 year lifetime of system and the differential between fuel contribution to COE and the US average residential price for electricity (8.57 ¢/kWh).

# Summary

– **SOFCs operate at higher electrical conversion efficiencies than PEMFCs, do not require CO removal, do not require humidification of the anode and cathode gases, and generate higher quality waste heat that can be better used for fuel reforming, space heat, or domestic hot water applications.**

– **While it is perceived that PEM fuel cells have shorter start-up times than SOFCs, a PEMFC system that includes reforming of methane has a start-up time that is comparable to that of SOFC because both are governed by the transient response of the fuel processor.**

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